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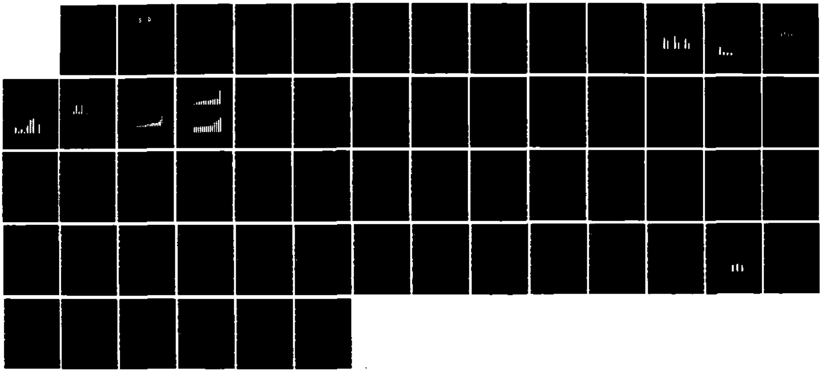

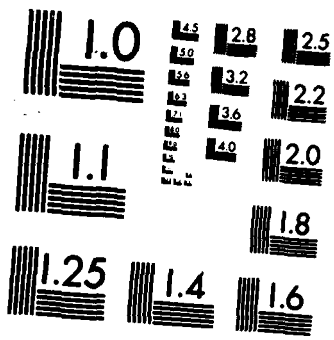

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Report No. 860601

EVALUATION OF SHIPBOARD RELIABILITY OF AN/BQQ-5 SWITCHED-MODE POWER SUPPLIES

by

Greg D. Raskin
R. Grant Lannon
Dwight O. Monteith, Jr.

prepared for

Naval Sea Systems Command

July 1986

DOM ENGINEERING SERVICES, INC. 1002 WEST AVENUE, AUSTIN, TEXAS 78701 512-477-6011

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Acknowledgments

The switching power supply reliability accomplishments on the AN/BQQ-5 program are the result of a concerted effort within the Navy and IBM Federal Systems. Within these institutions, there are a number of individuals who can be considered as principal contributors to the results presented herein. It is the nature of reliability that the success of this program can only be determined ten years after the fact, if at all. We have identified the following contributors.

Navy:

Don L. Baird, NAVSEA
Willis J. Willoughby, Jr., NAVMAT

IBM:

Gerald D. Brode
George E. Dailey
G. William Mesick
Carl A. Napolitano
William C. Singleton
Holmes W. Somers
Robert J. Vasilow

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I. INTRODUCTION

A. Purpose of the Report

The IBM power supply units in the AN/BQQ-5 sonar system have established a record of reliable performance over the course of ten years of system operation. Due to their excellent field performance, these units provide a model for present and future Navy power supply programs. Future power supply designs can make use of this model in several ways:

Actual shipboard reliability of critical power supply components can be analyzed to determine primary failure modes, and the lessons learned can be applied to new power supply designs.

Component technology improvements developed during this program can be used to augment the reliability of new designs.

Manufacturing methods used in this program, such as burn-in and parts screening procedures, can help to improve the reliability of new designs.

The actual failure rates of critical power supply components can be referenced to failure rates predicted from MIL-HDBK-217. The results of this comparison can be used for updating MIL-HDBK-217 predictions for power supplies, which in turn can be used by other Navy power supply procurement programs to achieve more accurate reliability predictions.

The lessons learned from the AN/BQQ-5 program can be used by the Navy to establish program requirements for future power supply acquisitions.

B. Objectives of the Effort

Many of the guidelines for the development of reliable power supplies outlined in NAVMAT P4855-1 were developed in response to the initial reliability problems experienced by the AN/BQQ-5 program.

The objective of this effort was to document the actual shipboard reliability achieved by the AN/BQQ-5 power supplies and to document the methods used to obtain this reliability. Power supply reliability would be calculated and compared to updated reliability predictions. This comparison would serve as a reference for the reliability prediction process for power supplies as well as identify the applied technology developed under this program for use in present and future equipment programs developed under NAVMAT P4855-1 guidelines.

The DOM Engineering Services Inc. (DOMES) approach to evaluating reliability consists of the following steps:

Identifying and characterizing the failure and nonfailure power supply populations.

Determining the critical components in the power supply designs.

Screening repair records to isolate primary failure mechanisms from ripple-through failures and routine replacements.

Creating a data base containing manufacture dates, failure dates, and repair data.

Updating the original reliability predictions using MIL-HDBK-217D.

Analyzing and comparing measured reliability with the predicted reliability.

Determining any correlation between electrical and thermal stress and achieved MTBF.

Calculating MTBF trends over time and determining any correlation with design changes and burn-in modifications.

C. Relationship with NAVMAT P4855-1

The methodology and component selection, screening, and derating used to achieve the shipboard reliability discussed has been incorporated into the power supply design recommendations presented in NAVMAT P4855-1. Therefore, the AN/BQQ-5 power supply performance identified herein can be considered a case history in support of the P4855-1 guidelines. The

extent to which the AN/BQQ-5 power supplies conform to NAVMAT guidelines is presented in the Appendix which shows that all critical components meet these guidelines.

D. Description of Report

Section I introduces the global objectives of the project.

Section II gives a brief summary of results including overall power supply MTBF, and MTBF versus shelf time, manufacture date, and load environment. Reliability of capacitors is also discussed.

Section III describes the specific objectives for the study and the data required to meet those objectives. The analysis method to achieve the objectives is also described.

Section IV compares the data required for the original objectives with the data that was obtained. The revised objectives for the project are described. Revisions to analysis methods are detailed. Finally, the confidence limits and correction factors associated with the results are described.

Section V gives the location of the detailed analysis in the Appendix sections for each of the three types of power supplies. This section also gives the conclusions and recommendations resulting from the detailed analysis.

II. BRIEF SUMMARY OF RESULTS

A. Brief Summary of Significant Results

The DOMES measured reliability analysis of the three power supplies examined produced the following conclusions:

1. Available data indicates that the AN/BQQ-5 power supplies are indeed very reliable and exceed original IBM predicted MTBF by a factor in the range of from 1.6 to 3.5; and MIL-HBK-217D predictions by a factor in the range of 4.5 to 7.0.

2. Available data is inadequate to obtain statistically significant data on power supply component or module reliability.

3. Extended non-operating shelf time significantly reduces power supply MTBF.

4. Power supply loads and application environments have a significant impact on MTBF.

5. New manufacturing processes have increased the MTBF of aluminum electrolytic capacitors by an order of magnitude.

6. The guidelines for data collection and accession summarized in Part 2 of this report should be used as a guide for reliability program data requirements for future acquisition programs.

B. Confidence in Results

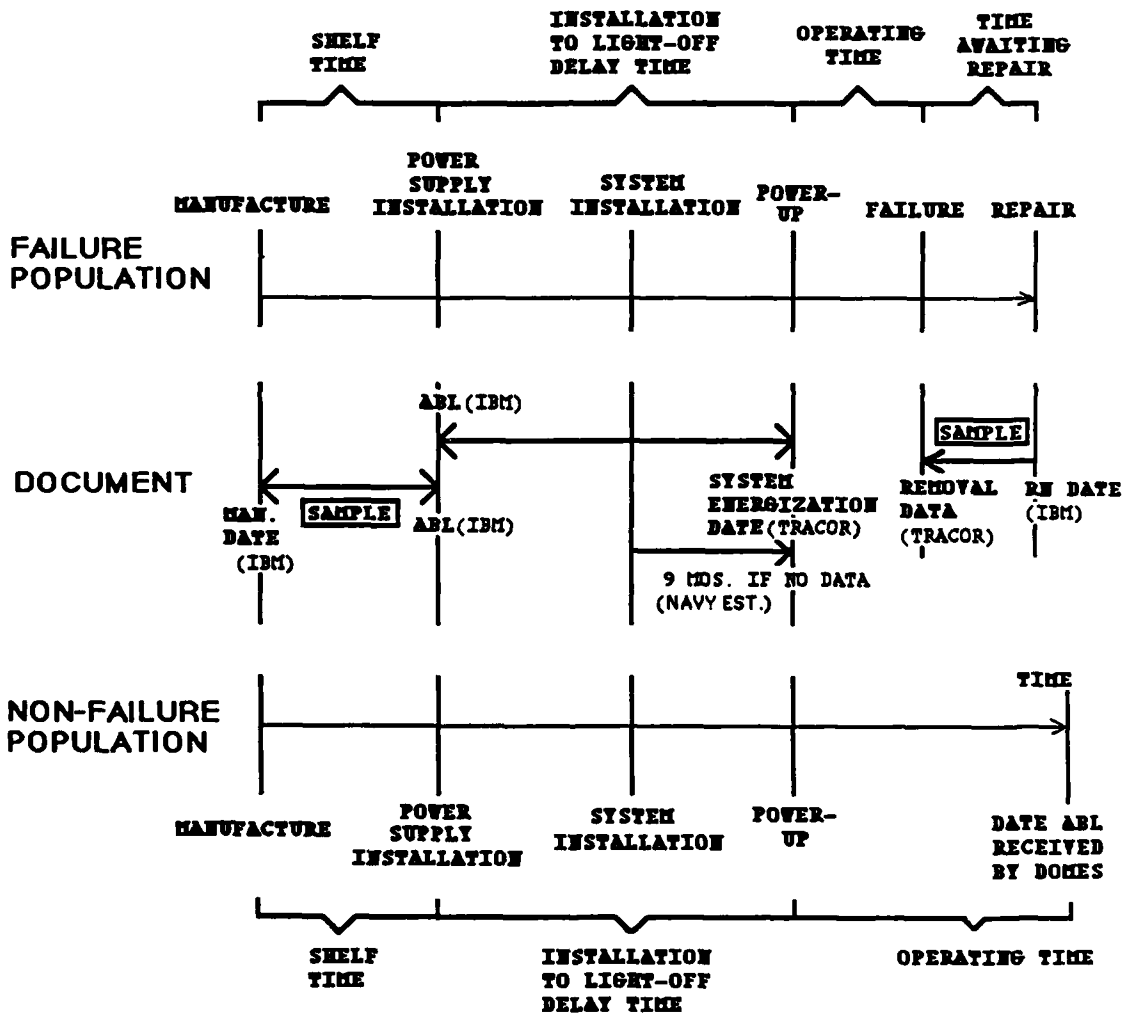
Complete data is apparently unavailable for power supplies in the AN/BQQ-5 system. Note however, that no organization was tasked or funded to collect and maintain records that would have supported the original objectives. This lack of data prevented the measured reliability analysis from producing statistically valid results and resulted in reliability figures that are inaccurate in the absolute sense. The data was complete enough to provide useful information on the AN/BQQ-5 power supplies relative to reliability trends and environmental factors which affect reliability,

Where there was doubt as to the completeness of the data, and independent sources of data existed that allowed computation of a correction factor, this factor was applied to the measured reliability figures.

C. Overall Power Supply MTBF

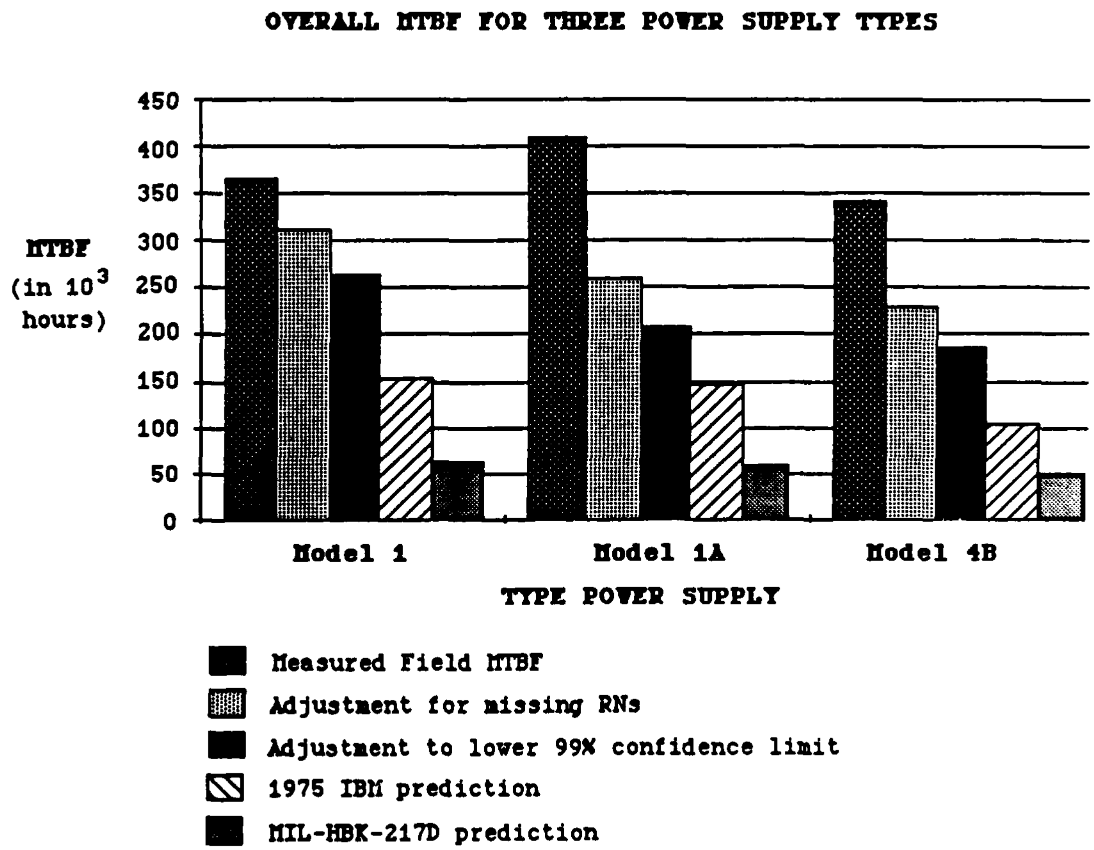
For our investigation of the AN/BQQ-5, we selected three power supply types used in the system: Models 1, 1A, and 4B. These three models comprise over fifty percent of the low voltage power supplies used in the system. Models 1 and 1A are +5-volt, 70-amp supplies, while Model 4B is a multiple output supply consisting of +15 volts at 5 amps, +15 volts at 7 amps, and -15 volts at 7 amps. Input power to the power supplies is 115 volts AC, 60 Hz, three-phase, delta-connected.

The following diagram shows how available data from IBM and other sources were used to establish operating time for failed and non-failed power supplies. The total operating time was divided by the total number of failures to obtain the measured overall MTBF of the power supplies.



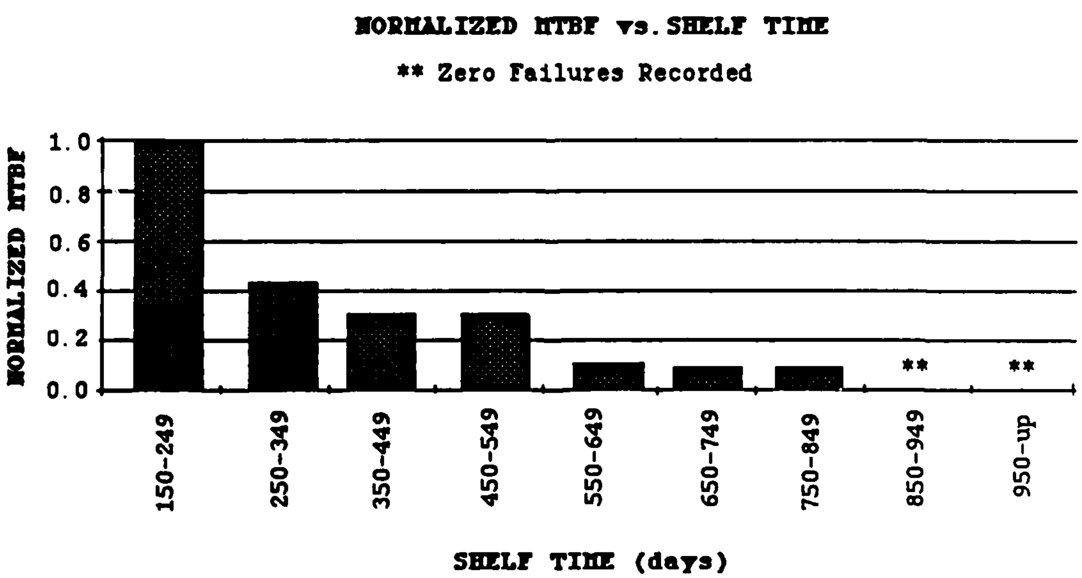
NOTE: SAMPLE MEANS AVAILABLE DATA WAS USED TO CALCULATE AN AVERAGE WHICH WAS USED IN INSTANCES WHERE THERE WAS MISSING DATA. FOR EXAMPLE, IN CASES WHERE THERE WAS NO DATA ON TIME AWAITING REPAIR FOR A CERTAIN SUPPLY, THE AVERAGE OF ALL CALCULATED TIMES AWAITING REPAIR WAS APPLIED TO THAT PARTICULAR POWER SUPPLY.

The overall MTBF for the three power supplies was corrected for missing Reject Notices (RNs) as estimated from a second source of information. The change in the MTBF because of missing RNs was calculated. Finally, the 99% lower confidence limit was calculated for all three corrected MTBF calculations. The result is shown below with the DOMES measured MTBF of the first column being reduced by the missing RN factor and the lower 99% confidence limit factor. Also shown is the original MTBF predicted by IBM in 1975 and the updated MIL-HDBK-217D prediction performed by DOMES.

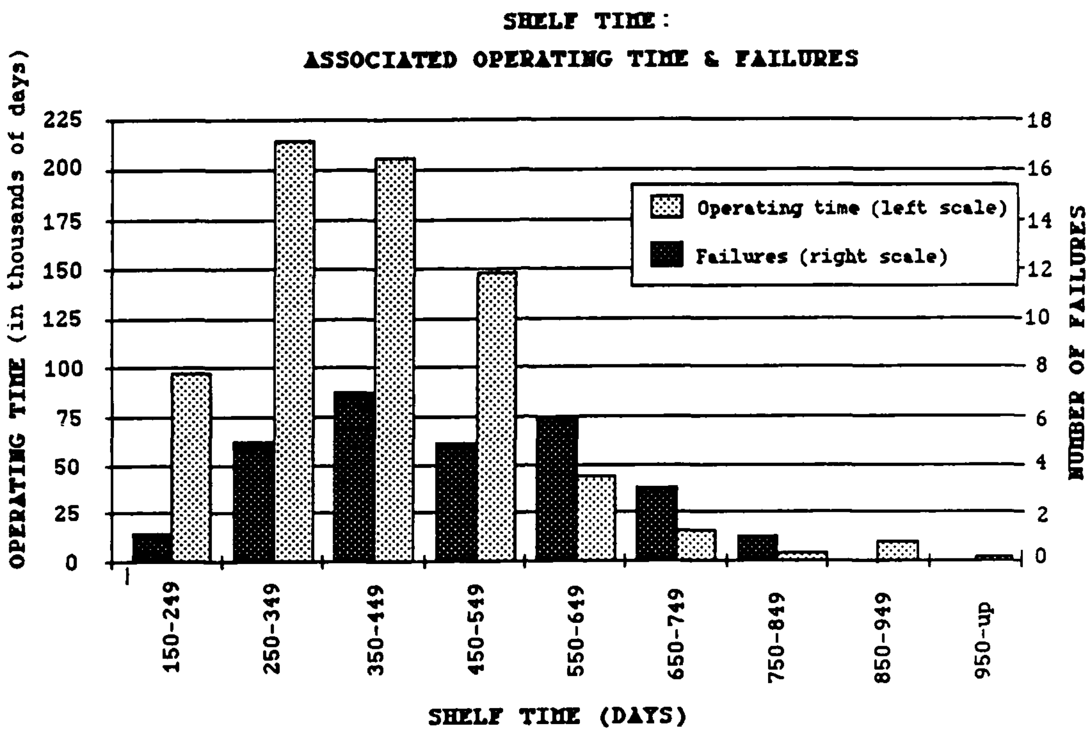


D. MTBF vs. Shelf Time

The method used for calculating MTBF as a function of shelf time consists of first determining the range and distribution of shelf time values from the available data. This range is divided into equal segments or ranges. MTBF is then calculated for each segment as the sum of nonfailure operational time plus the sum of failure operational time, which is divided by the number of failures in that segment. The result is a discrete group of MTBF data which can be plotted as a function of increasing shelf time. The number of ranges is limited by the number of failures available in the shelf time analysis, in that each range should have at least one failure to produce a finite MTBF figure for that range. On the other hand, it is desirable to have a significant number of ranges in order to show trends more clearly. The actual number of ranges chosen is a compromise between these opposing requirements. Please note that the graph is normalized due to incomplete manufacture date data and that due to the relatively small number of failures, the shape of the histogram could change with a different selection of time segments. Sufficient manufacture date data to perform the shelf time analysis was available only for the Model 4B.



The following chart shows the operating time and number of failures associated with each shelf time segment:



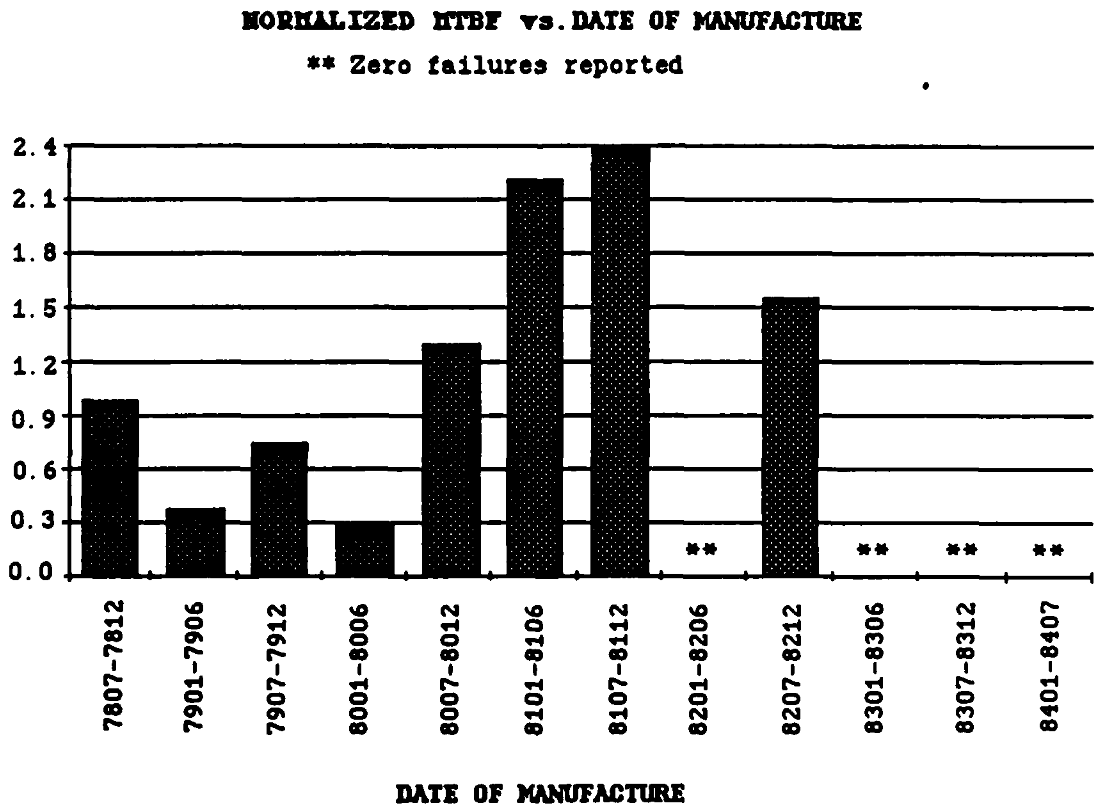
Below is a list of failure modes for those Model 4B failed power supplies in all of the shelf time categories:

FAILURE CATEGORY	NUMBER OF FAILURES
Capacitors	5
Transistors	3
Linear IC	2
Diodes	2
Resistors	1
Solder Connection	1
Assembly Error	1
No Data	6
Unspecified	3

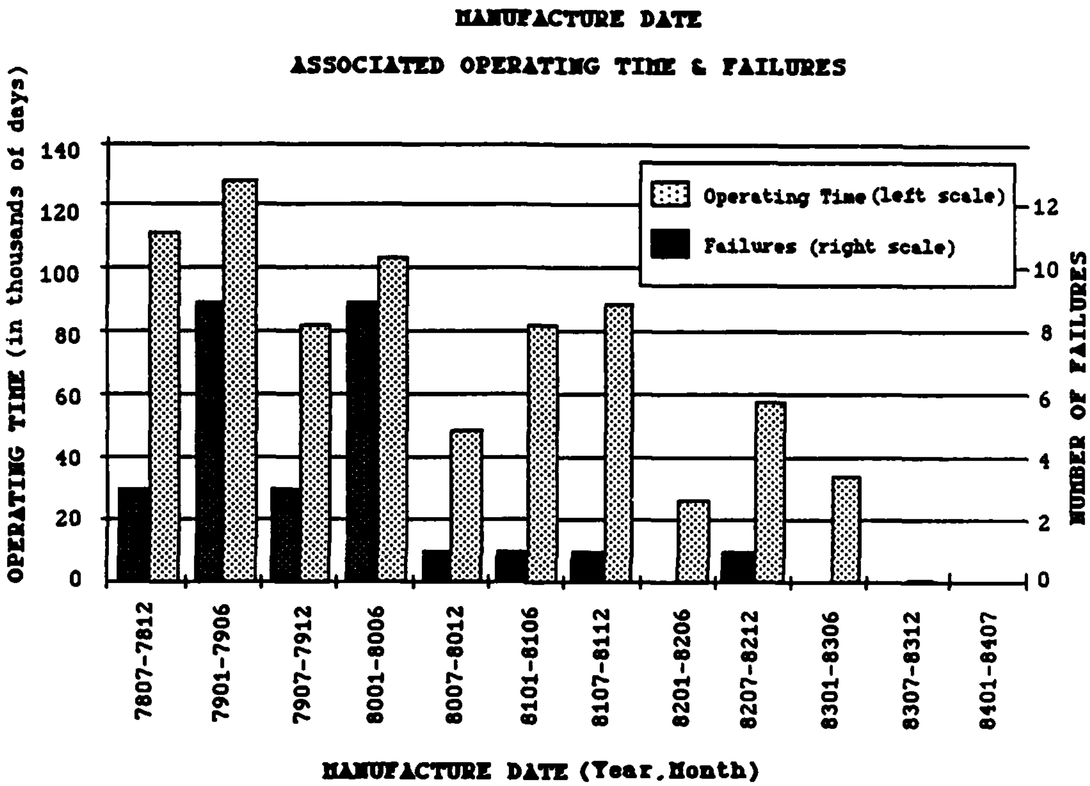
The large number of failures without failure mode data relative to the total number of part failures recorded makes interpretation of this data uncertain at best. However, if the assumption is made that the group with failure mode data represents a random sample of all failures in this category, it can be concluded that while capacitor failures represent the greatest frequency of failure, no truly predominant failure mode exists. A larger sample with more reliable failure mode data would allow this type of analysis to produce more accurate results.

E. MTBF vs. Date of Manufacture

The method used to calculate MTBF as a function of date of manufacture is similar to the method used for shelf time calculations, except the range of manufacture dates is divided into discrete segments. Interpretation of the results in this section include the same qualifications presented in the shelf time section. Sufficient data was available only for the Model 4B.



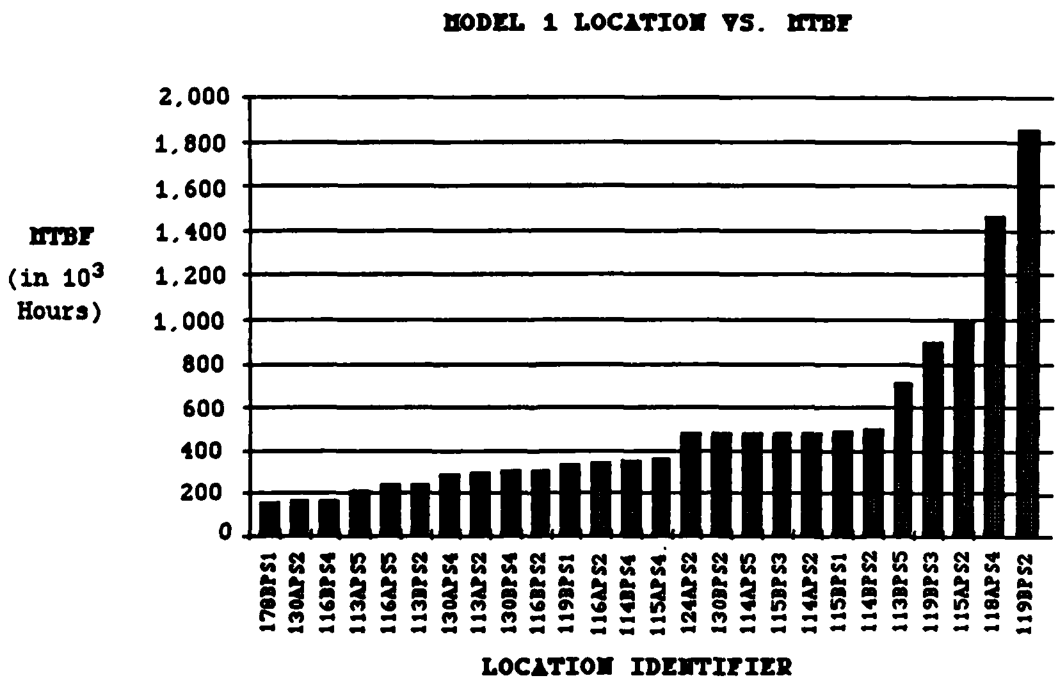
The associated operating time and number of failures for each manufacture date time segment is shown below:

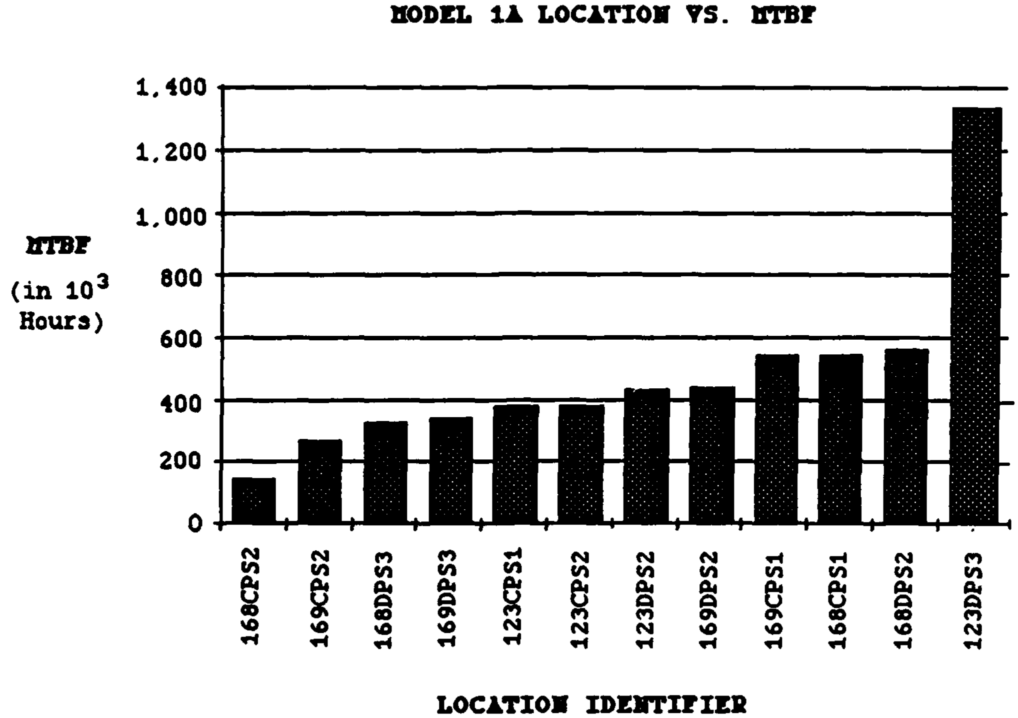


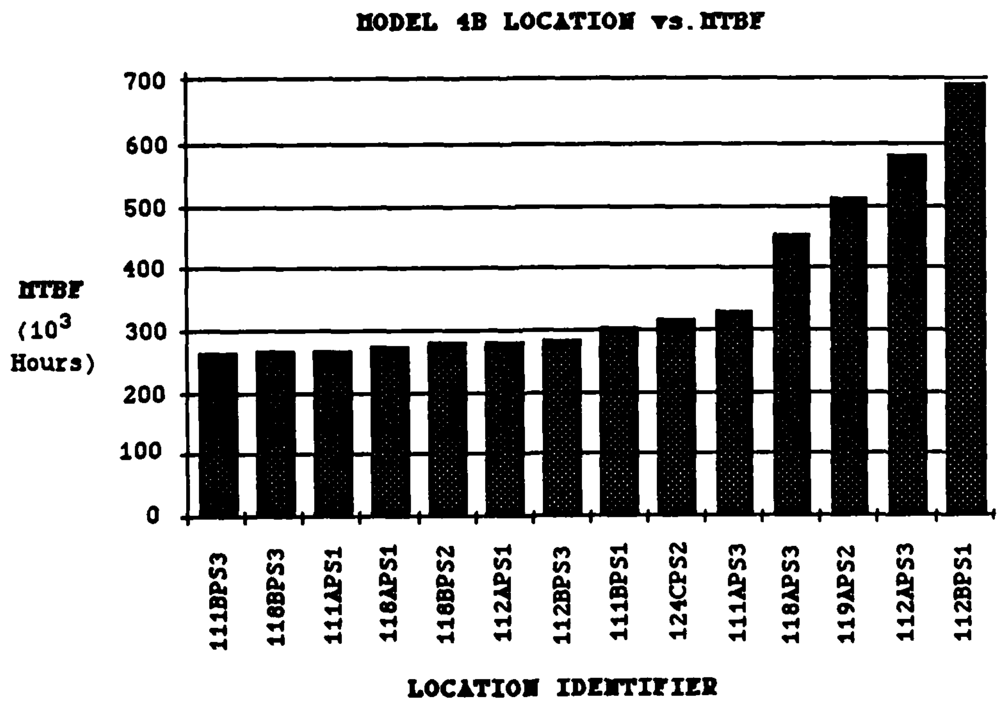
F. MTBF vs. Electrical and Thermal Stress

The "load environment," for the purpose of this analysis, is assumed to be defined by the reference designator specification for a particular supply. Specific information concerning the actual electrical and thermal stress applied to the supplies by each reference designator in the system was not available. This analysis therefore can only point out which locations in the system are conducive to long or short-lived power supplies. The actual electrical and thermal environments can be studied in the future to determine if there is any correlation with the MTBF figures developed here for reference designators.

In this analysis, the combined failure and nonfailure data base was sorted by reference designator and serial number. Each reference designator was treated as a subpopulation. The total operational time was developed as the sum of the nonfailure operational time plus the sum of the failure operational time. To determine MTBF, the total time was divided by the number of failures in the subpopulation. The three graphs on the next two pages show the results of this analysis for each of the three power supplies.




MODEL 1A LOCATION VS. MTBF
MTBF
(in 10^3 Hours)
1,400
1,200
1,000
800
600
400
200
0
168CPS2
169CPS2
168DPS3
169DPS3
123CPS1
123CPS2
123DPS2
169DPS2
169CPS1
168CPS1
168DPS2
123DPS3
LOCATION IDENTIFIER


MODEL 4B LOCATION vs.MTBF
MTBF
(10^3 Hours)
700
600
500
400
300
200
100
0
111BPS3
118BPS3
111APS1
118APS1
118BPS2
112APS1
112BPS3
111BPS1
124CPS2
111APS3
118APS3
119APS2
112APS3
112BPS1
LOCATION IDENTIFIER

G. Observations on Capacitor Reliability

The difference between the measured reliability and the predicted reliability for critical aluminum electrolytic capacitors in the system based on MIL-HDBK-217D (the updated prediction) was an order of magnitude in some cases, but very slight in others. The capacitors that exhibited the greatest discrepancy are the input rectifier filters. These capacitors are known to have been upgraded to high-purity foil electrolytics with epoxy end-cap seals during the lifetime of the system, and they exhibit an order of magnitude greater reliability than the model in MIL-HDBK-217D. However, a filter capacitor in the feedback loop of the auxiliary housekeeping supply (C1, A1A3), which exhibited a high failure rate, produced a measured reliability which was very close to that predicted by the model in MIL-HDBK-217D.

The implication of this discrepancy is that the model in MIL-HDBK-217D, while accurate for standard electrolytics, is inadequate for the newer, high-reliability aluminum electrolytics, and that an extension of the model would be appropriate to represent these capacitors.

III. OBJECTIVES AND METHODS OF ANALYSIS

A. Original Objectives

The central focus proposed for the project was to determine the achieved field reliability of critical power supply components. The results would then be compared with updated component reliability predictions based on MIL-HDBK-217D. This comparison would serve as a reference for future updates to the reliability-performance design and prediction processes concerning switched-mode power supplies.

In addition, an analysis was proposed to determine any correlation between shelf time and MTBF. This was to be accomplished by determining the elapsed time from date-of-manufacture to date-of-installation for the supplies, then tracking the MTBF performance for units that fell into various shelf time categories. Also proposed was an analysis to correlate load environment to achieved MTBF. The electrical and thermal stress applied to the supplies for each reference designator (supply location within the system) was to be determined.

On a secondary level, the component screening and/or manufacturing methods that were used to increase reliability were to be determined and documented. Also, changes in burn-in procedures were to be determined, and their effect on reliability calculated. Engineering Change Notice (ECN) documents were to be examined to determine what effect design changes had on reliability.

On a tertiary level, the achieved overall shipboard MTBF was to be calculated for the three supplies using the repair and installation data.

B. Data Required for Original Objectives

The original data request was based on the requirements for a complete reliability analysis of the power supplies from their introduction into service to the present time. Sufficient data would be obtained to determine the field reliability of critical components, overall power supply MTBF, and other factors that affect reliability. The data would contain a time trail of events in the power supplies' lifetime, including: manufacture date, installation date, power-up date, date of failure, date of removal, and repair date.

The data requested to meet the objectives is as follows:

1. Manufacture data to include serial numbers and dates of shipment of all supplies.

2. System information to include serial numbers of supplies in each system, reference designator of each supply, system serial number, the boat in which the system was installed and the date of installation.

3. Power supply repair information to include power supply serial number, date of removal, boat removed from, dates of repairs, replaced components, and date of shipment back to depot.

4. Power characteristics for each reference designator to include loads and duty cycle.

5. Engineering change information to include date of implementation, details of the change, and supplies affected.

6. Burn-in procedures, changes to them, dates of changes, and supplies affected. This included any changes to the design as a result of using the original/revised burn-in procedures.

7. Changes to electrolytic capacitors to include epoxy end-cap modifications. Identification of affected supplies and dates the changes took place.

8. Any other significant changes that could have affected reliability of the supplies.

C. Method of Analysis for Original Objectives

The overall power supply population was to be determined from manufacture and installation data, while the failure population was to be determined from repair data. Nonfailure supplies were defined as those power supplies in the overall population which did not appear in repair data.

Achieved MTBF was to be calculated by examining the repair records for the MPS Models 1, 1A, and 4B to determine the failure population. The operational time information contained in the primary failure and nonfailure populations would then be used to produce an MTBF figure.

Schematic data was to be used to identify the critical component groups within the design.

Parts that were replaced during a repair and information provided by technician's notes were to be used to produce an engineering estimate of the primary failure mechanism. Primary failure mechanisms were to be isolated from secondary failures, which often occur in power supplies as a result of overstress conditions following the initial part failure.

A reliability analysis program written by DOMES was to be used to update the original reliability predictions to MIL-HDBK-217D. The original predictions were also to be reviewed for accuracy and completeness, and any necessary corrections were to be performed during the updating procedure.

Statistical algorithms were to be programmed into Symphony and applied to the spreadsheet data base to calculate measured reliability data for power supply populations, modules, and components. The results were to be compared

with the corresponding original and updated predictions.

The data base was to be analyzed to determine if the operating environment of the power supplies (electrical and thermal stress) affected their achieved MTBF.

The data base was also to be analyzed to determine any correlation between the shelf time experienced by the power supplies and their achieved MTBF.

And finally, the behavior of MTBF over time was to be determined to illustrate reliability trends, which were then to be correlated with design changes or burn-in modifications that occurred during the lifetime of the system.

IV. REVISED OBJECTIVES AND METHODS OF ANALYSIS

A. Data Obtained

The portion of the required data obtained was insufficient to fully meet the original objectives. Note however, that no organization was tasked or funded to collect and maintain records that would have supported the original objectives.

A brief summary of the obtained data is as follows:

The reject notice (RN) information obtained consisted of two distinct groups of data from two locations within IBM. The information contained in these two groups was inconsistent, one group containing considerably more data than the other on failure mode and parts replacement. Computer listings of RN information were also obtained, but contained insufficient information to isolate failure modes. A cross check of RN information sources indicated that all of these historical files were incomplete representations of the actual RN population.

A partial list of manufacture dates was obtained. This list lacked information on a majority of the early power supplies.

Engineering Change Notices (ECNs) were received and most appeared to concern only minor schematic changes. ECNs could not be associated with power supply serial number range due to the lack of manufacture date data.

Tracor Inc. maintained information on removals from the Navy "3M system" on a sample of 16 boats.

Pete Asman formerly of NAVSEA, Code 06C, kept a book of removal actions from selected hulls during the period 1977-1981. This removal matrix and associated information was used to check the completeness of RNs and to supply other data related to removals. This information is referred to in this report as the Asman book.

Tracor also provided a list of overhaul dates for hulls which received an AN/BQQ-5 system including start, completion, and energization dates. This data provided information on initial installation and power-up of installed systems.

An As Built List (ABL) supplied by IBM gave a comprehensive representation of power supply installations, excluding replacement installation.

Power supply schematics for the three types of power supplies were obtained.

The original reliability predictions on all three types of power supplies were provided after an extensive search to locate them.

The following data from the original requirements list was not available:

1. Information on electrical and thermal stress for the reference designators in each of the three types of power supplies.

2. Information on overall burn-in thermal cycling profile and temperature soaks, except for one change in burn-in procedures that took place in 1976

3. Information concerning those supplies that were manufactured or retrofitted with epoxy end-seal electrolytic capacitors.

B. Revised Objectives

Critical component achieved field reliability would be determined and this result compared to updated component reliability predictions based on MIL-HDBK-217D. If data was

not sufficient to calculate an absolute number, scaled MTBF numbers would be used to give a comparison of critical component MTBFs in a relative sense.

Correlation between shelf time and MTBF was to be determined based on those power supplies for which manufacturing and installation data existed. Relative measures would be used if data was inadequate for absolute MTBF calculations.

Correlation between MTBF and manufacturing date would be examined in a manner similar to the shelf time analysis.

Electrical and thermal stress environment versus MTBF would be determined for power supplies only in terms of their reference designator within the system.

Component screening, manufacturing methods, and burn-in effects on power supply field reliability would not be analyzed.

Engineering changes and their effect on field reliability would not be analyzed.

Overall shipboard power supply MTBF would be calculated from available data for each power supply. Where independent sources gave a quantitative measure of missing data and a correction factor could be calculated, this factor would be applied to the data. Overall achieved field reliability would be calculated for each of the three types of power supplies and confidence limits would be applied to the results to determine the statistically valid lower limits of achieved reliability.

C. Methods of Analysis for Revised Objectives

1. Measured Reliability Data Base and Achieved MTBF

Lotus 1-2-3 and Symphony were used to create a failure data base which cataloged all failure data in a spreadsheet format and allowed computerized analysis of large populations. Nonfailure power supply data from the ABL was also entered in a spread sheetformat. These two spreadsheets were combined to form the data base for measured reliability analysis.

A Lotus 1-2-3 spreadsheet was used to create a failure data base that combined all repair information into a single document. A separate group of records was created for each

power supply type. Each record includes fields for serial number (PS SN), manufacture date (MFGR DT), reference designator (REF. DESIGNATOR), installation date (INST DT), hull number (HULL NO.), RN number (RN NUMBER), and RN date (RN DATE). This is followed by five binary yes/no fields that indicate the sources of repair information for that particular power supply. These fields provide indication of whether the power supply serial number appears in the hard copy RN material (RN HARD COPY); whether it appears on the ABL list (ABL); whether it appears on the Manassas computer data-base output (COMP LIST); whether it appears in the removal records maintained by Pete Asman (ASMAN BOOK); and whether it appears in the Owego computer data-base output (OWEGO LIST). These fields are followed by module failure codes and part failure codes.

The ABL was obtained in disk format as a text file and transported to a Lotus 1-2-3 spreadsheet file. The failure data base was merged with the ABL spreadsheet with the failed power supply serial numbers taking the place of the corresponding serial numbers on the ABL. Failed power supply serial numbers which did not appear on the ABL were considered spare failures and were eliminated. Operational time was then calculated for all entries on this merged list. Operational time for nonfailure supplies was determined by first calculating the elapsed time between the installation date and the date that the ABL list was received by DOMES (ABL date). The installation-to-light-off delay time was obtained from the look-up table by referencing the hull in which the system was installed. This delay time was subtracted from the previous calculation to obtain the final operational time figure. If the result of this subtraction was less than zero, then it was assumed that the supply had not been fired up and zero was used as the final operational time figure. Operational time for failed supplies was determined by first calculating the elapsed time between the installation date and the RN date. The installation-to-light-off delay time was obtained from the look-up table and subtracted from the previous calculation. The average time-awaiting-repair was also subtracted, yielding the final operational time figure. Negative values for this figure are the result of the application of an average time-awaiting-repair figure.

For nonfailure supplies with multiple installation listings in the ABL, the latest installation date was used in the calculation. For failed supplies with multiple installations, the latest installation date not later than the RN date was

used in the calculation. Failed supplies were considered spare failures if the installation date occurred after the RN date. These supplies were eliminated from the spreadsheets. Any failures listed in the Asman book and the ABL, but not in the IBM repair data, were included as failures for the MTBF calculations. Since the Asman book does not specify removal dates or RN dates, an exact figure for operational time is not available for these power supplies. To compensate for this, the average operational time for all other failed supplies was calculated and applied to the Asman failures. To calculate an overall MTBF figure, the operational time for all the nonfailure supplies was added to the operational time for all the failed supplies and the result was divided by the number of failures.

2. Failure Mode--Analysis of Hard Copy RNs

Each hard copy RN was individually reviewed to isolate the primary failure mode from ripple-through failures and routine part replacements. In some cases, insufficient data existed on the RN to determine the failure mode. Failure mode data that was derived from this material fell into two categories: module failure and part failure. Some RNs provided both module and part failure data, some only module data. Most of the failures listed on the computer data-base outputs (for which we did not have hard copy RNs) provided no module or part failure data. The hard copy RN material from IBM, Manassas, although covering a limited time period, did provide a great deal of information about the repair that was performed. This allowed an engineering estimate to be made of the primary failure mechanism. The material from IBM, Owego, on the other hand, proved to be very incomplete, generally listing only the modules that were repaired and referring to a great number of RNs for which we have no record. These inconsistent records prevented us from obtaining a comprehensive picture of failure modes on either the part or module level, and created the need to introduce population "scaling" methods in order to obtain "ball park" reliability figures for parts and modules. The procedures used to calculate part and module MTBFs are covered in a later section.

3. Module MTBF and Part Failure Rates

Only a portion of the failure data base contains information on module failures, and only a portion of that contains

information on part failures. In order to determine measured reliability for modules and parts, it was necessary to scale the nonfailure data base such that it was proportional to the reduction in size of the failure data base caused by the lack of data. The following outlines the procedure used: let the sum of the nonfailure operational time be represented by Ta, and the sum of the failure operational time be represented by Tb. Further, let the total number of failure data items be represented by N, and the number of failure data items with module failure information be represented by m. The scale factor is then m/N. The scaled total operational time for nonfailure supplies is Tc, where Tc = (m/N) * Ta. The MTBF for a module is then calculated as time Tc plus the total operational time of failed supplies with module data, which is divided by the total number of failures of the module in question.

Similarly, the failure data population with module data divides into a segment with part failure data, and a segment without. If the number of failure data items with parts data is represented by j, then the second scale factor is j/m. The scaled total operational time for nonfailure supplies is now Td, where Td = (j/m) * Tc. The MTBF for a part is then calculated as Td plus the total operational time of failed supplies with part data, which is divided by the total number of failures of the part in question. The reciprocal of MTBF is the part failure rate.

4. Average Time Awaiting Repair

The date that appears on a particular RN does not represent the time at which the supply failed. Rather, it is the date that the repair process commenced on that supply. There is a period of time from when the supply actually failed on the ship to when it makes its way to IBM to be repaired. To gain a better idea of when the supply actually ceased to operate, an estimate is made of this average time awaiting repair. An analytical estimate was arrived at by using the power supply removal data from Tracor. Since serial numbers were not recorded, the supplies had to be traced through their reference designator and the hull number. A total of 12 supplies were successfully traced in this manner. The average time span from the supply removal date on the Tracor data to the RN date on the IBM data was eight months for this sample. Tracor relayed an estimate to us from the BQQ-5 Integrated Logistics Support group of 180 days, or approximately six months. Due to the uncertainties involved in the repair data

base that we employed in our analytical estimate, we elected to use the ILS estimate of 180 days in the MTBF calculations.

5. Installation To Light-Off Time Delay

The installation date on the ABL represents the date that a BQQ-5 system was shipped from IBM. There is a delay from this date to the date that the system was installed on a ship and energized. Tables of hull number, overhaul start, completion, and energization dates supplied by Tracor allowed us to produce a look-up table in our data base, which specified this delay time for a given hull number. The look-up data are shown in Table B1 of the Appendix. Since the ABL lists only supplies that were originally installed in a BQQ-5 system, virtually all power supplies with a given hull specification have the same installation date. Multiple overhaul dates sometimes appeared for hulls in the Tracor data base. If a system energization date was available that applied to the correct overhaul, the difference between this energization date and the installation date was used in the look-up table. If an energization date was not available, but an overhaul start date was given, nine months were added to the start date to serve as an estimate of the system energization date. The difference between this date and the installation date was then used in the look-up table. An average delay time was calculated from this subset of hull numbers and applied to the balance of hulls for which no delay time calculation was possible.

C. Confidence in Results from Available Data

1. Missing RNs

The Asman book was an independent source of removal information that covered all hulls then operational. At the time it was kept, entries in the Asman book that did not later appear in the IBM repair system were eliminated. Therefore, it was assumed that entries in the Asman book for which there was no corresponding repair data represented data that originally existed at IBM but was not located for this study. The Lotus data base was examined to determine the number of times removals were noted in the Asman book but not found in IBM repair data. The percentage of non-documented Asman failures was converted into a correction factor for each power supply and applied to the measured MTBF for that power supply. The results are shown in the Appendix and in the summary of

results. The confidence limit calculations described in the next section were applied to the adjusted power supply MTBFs.

2. Confidence Limits

The Chi-Square distribution was used to determine the confidence limits for the calculated overall MTBF for each power supply. An assumption was made that the sample used would be the same as obtained from a time truncated test. The sample is very large, and therefore the 99% lower confidence limit was calculated with the belief that the lower limit would not be significantly different than the calculated MTBF. The formula for the lower confidence limit using the Chi-Square distribution is:

$$\theta_L = \frac{2T}{X^2_\alpha\ (v=2N+2)}$$

where: θ_L = Lower Confidence Limit
T = Total Test Time
α = Confidence Level
N = Total Number of Failures
v = Degrees of Freedom

The sample is very large because the number of failures for the three power supplies varies from 72 to 189. For this situation, a normal approximation of the Chi-Square distribution can be used (i.e., this approximation gives the number

to be inserted in the denominator of the confidence limit formula). The normal approximation formula is:

$$X_{\alpha}^{2} = v\left(1 - \frac{2}{9v} + z_{\alpha}\sqrt{\frac{2}{9v}}\right)^{3}$$

Where z_{α} = the normal deviate, the value of x for which F(x) is the desired percentile. F(x) for the two sided 99th percentile confidence limit is 2.576. The results obtained from the calculation of the confidence limits and a figure showing the resulting lower limit compared to the adjusted measured MTBF is shown in the appendix.

V. RESULTS OF ANALYSIS

The results of the analysis are presented in the Appendix. Refer to the key on page two of the appendix for the module and part codes used in the DOMES analysis.

A. Model 1

Table A1 lists the measured failure rate for every part listed in the DOMES failure data base as a primary failure, with a comparison to the MIL-HDBK-217D prediction.

Table A2 lists the measured failure rate for groups of critical components, and the original and updated predictions for these parts.

Table A3 lists the calculated MTBF for individual modules, and the original and updated predictions for these modules.

Table A4 shows the calculated overall MTBF, and the original and updated predictions for the Model 1.

Table A5 shows the calculated MTBF for each reference designator.

B. Model 1A

Table A6 lists the measured failure rate for every part listed in the DOMES failure data base as a primary failure, with a comparison to the MIL-HDBK-217D prediction.

Table A7 lists the measured failure rate for groups of critical components, and the original and updated predictions for these parts.

Table A8 lists the calculated MTBF for individual modules, and the original and updated predictions for these modules.

Table A9 shows the calculated overall MTBF, and the original and updated predictions for the Model 1A.

Table A10 shows the calculated MTBF for each reference designator.

C. Model 4B

Table A11 lists the measured failure rate for every part listed in the DOMES failure data base as a primary failure, with a comparison to the MIL-HDBK-217 prediction.

Table A12 lists the measured failure rate for groups of critical components, and the original and updated predictions for these parts.

Table A13 lists the calculated MTBF for individual modules and the original and updated predictions for these modules.

Table A14 shows the calculated overall MTBF and the original and updated predictions for the Model 4B.

Table A15 shows the calculated MTBF for each reference designator.

Table A16 shows the calculated MTBF versus manufacture date.

Table A17 shows the calculated MTBF versus shelf time.

Table A18 and Figure A3 shows the RN discrepancies between the Asman book and the IBM RNs and the effect on measured MTBF for each of the three types of power supplies.

Table A19 shows the results of the calculation of the lower confidence limits for each power supply and the effect of their application to the measured overall power supply MTBF.

Table A20 shows failure modes for the Model 4B supplies when they have greater then 350 days shelf time.

Table A21 shows the installation to light-off (power-up) delay time.

Table A22 shows the components in the Model 1, 1A, and 4B which exceed the NAVMAT P4855-1 guidelines.

D. Conclusions and Recommendations

Shipboard reliability of power supplies built to the guidelines of NAVMAT P4855-1 will significantly exceed the predictions of MIL-HDBK-217D.

The Navy should assume the responsibility for keeping detailed in-service and repair records so that the reliability of shipboard power supplies can be accurately measured. Diligent tracking of Navy in-service power supply reliability performance will allow "lessons learned" to be transferred to new acquisitions and reduce the costs associated with "reinvention of the wheel" in power supply design.

All new power supply procurements should be subjected to ongoing reviews to insure compliance with the NAVMAT guidelines.

Electrical and thermal stress derating, component quality, and environmental stress screening are the most significant contributors to power supply reliability.

Power supply contractors should be tasked to maintain historical records that give an overall picture of significant engineering changes, testing procedures, and other program changes which directly affect reliability so that reliability growth measurement can be ascertained at any time.

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[4] R. Grant Lannon, G. D. Raskin, and Dwight Monteith, Jr., "*Recommendations for Monitoring and Documenting* Reliability of Switched-Mode Power," DOM Engineering Services, Inc., July 1986.

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APPENDIX

Tables and Figures

APPENDIX

MODULE AND PART FAILURE CODE KEY

Module Codes

A = PS1	G = A4
B = A1A1	H = A5
C = A1A2	I = A6
D = A1A3	J = A8
E = A2	K = Undetermined
F = A3	-- = Unspecified

Miscellaneous Failure Codes

0 = No parts failure data exists
1 = Solder Connection
2 = Bad / Broken Wire
3 = PC Board Failure
4 = Mechanical Failure
5 = Assembly Error
6 = Broken Connector
7 = Unspecified Input Capacitor
8 = Unspecified Main Switch Transistor
9 = Unspecified Input Rectifier Diode
10 = Input Snubbers (R1, R2, C1, C2)
11 = Output Snubbers (R3, R4, C3, C4)
12 = Adjustment Required

Note: Part failure specifications consist of a module code followed by either a schematic designator or one of the miscellaneous failure codes.

==

MODEL 1: MEASURED ELECTRONIC PARTS FAILURE RATES

Total number of failures with module data	:	115
Total number of failures with parts data	:	87
Scaled hours, nonfailure group, Td	:	29,612,070
Total hours, failures with parts data, Tpd	:	2,462,232
Sum of Td and Tpd	:	32,074,302

Part Code	Failures	Failure Rate ----- (Per Million Hrs.) --- Measured	MIL-HDBK-217D	Experience Factor +
ACR1	3	.09353	.02310	.24698
ACR10	2	.06236	.02310	.37043
AS1	1	.03118	.01652	.52983
AS2	1	.03118	.01652	.52983
B0	20			
B2	2	.06236	---	---
B7	14	#		
B9	6	#		
C0	18			
C2	1	.03118	---	---
C8	5	#		
CCR5	2	.06236	.00203	.03255
CCR7	1	.03118	.00203	.06511
CQ1	1	.03118	.00749	.24022
CQ3	3	#		
CQ5	1	#		
CQ7	1	.03118	.00244	.07826
CR2	1	.03118	.00014	.00449
CVR2	1	.03118	.00727	.23316
D0	17			
D1	1	.03118	---	---
DC1	9	.28060	.56832	2.0254
DC3	1	.03118	---	---
DC6	1	.03118	---	---
DC8	1	.03118	---	---
DCR5	1	.03118	---	---
DHY1	7	.21824	---	---
DQ2	6	.18707	.00320 !	.01711
DQ3	1	.03118	---	---

Table A1. Model 1, Parts Failure Rates

MODEL 1: MEASURED ELECTRONIC PARTS FAILURE RATES

Part Code	Failures	Failure Rate (Per Million Hrs.) Measured	MIL-HDBK-217D	Experience Factor +
DR1	1	.03118	---	---
DR2	1	.03118	---	---
DT1	1	.03118	.30910	9.9134
DT2	1	.03118	.04614	1.4798
DU1	1	.03118	.02914	.93457
E1	1	.03118	---	---
E10	7	#		
E3	1	.03118	---	---
EC1	1	#		
EL1	1	.03118	.00018	.00577
ER1	2	#		
ER2	1	#		
ER8	1	.03118	.00072	.02309
ET1	1	.03118	.30877	9.9028
F0	8			
F3	1	.03118	---	---
FC22	3	.09353	.00014	.00150
FC25	1	.03118	.00014	.00449
FC26	1	.03118	.00013	.00417
FC8	1	.03118	.00021	.00674
FQ4	1	.03118	.00135	.04330
FQ7	1	.03118	.00085	.02726
FU2	2	.06236	.03021	.48845
FU4	1	.03118	.02502	.80244
FU5	1	.03118	.02502	.80244
FU6	1	.03118	.00956	.30661
FU8	1	.03118	.00989	.31719
FU9	1	.03118	.00956	.30661
FVR1	2	.06236	.00558	.08948
FVR3	1	.03118	.00484	.15523
G0	1			
H0	1			
HC1	1	.03118	.00016	.00513
HC2	1	.03118	.00016	.00513
HC3	1	.03118	.00016	.00513

Table A1. Model 1, Parts Failure Rates

MODEL 1: MEASURED ELECTRONIC PARTS FAILURE RATES

Part Code	Failures	Failure Rate ----- (Per Million Hrs.) --- Measured	MIL-HDBK-217D	Experience Factor +
HC4	1	.03118	.00016	.00513
K0	1			
K1	2	.06236	---	---
K2	5	.15589	---	---
K3	1	.03118	---	---
K4	3	.09353	---	---
K5	1	.03118	---	---
K6	7	.21824	---	---
KC21	1	.03118	---	---

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#: Please refer to the critical electronic part failure rate table.

!: This figure is for transistor Q8 on the discrete version of A1A3.

+: Experience Factor is the ratio of the MIL-HBK-217D prediction to the measured failure rate.

Table A1. Model 1, Parts Failure Rates

MODEL 1: CRITICAL ELECTRONIC PART FAILURE RATES

Component Group	Failures	---- Failure Rate (Per Million Hrs.) --- Measured	IBM Pred. (1975)	MIL-HDBK-217D
Main Switch Trans.	9	.28060	.72570	.02352
Input Capacitors	14	.43649	.19360	6.7026
Input Rectifiers	6	.18707	.01356	.00725
Primary Snubbers	11	.34295	.03474	.00589
Output Rectifiers	5	.15589	.14072	.04619
Output Capacitors	0	0.0	.39270	.05187
Aux. Switch Trans.	6 #	.18707	.03283 #	.00320 #
Aux. Hybrid	7	.21824	N/A +	N/A +
ICs, total	8	.24942	.43506	.20574
C1, A1A3	9	.28060	.01279	.56832

#: The six failures are for Q2, module A1A3, hybrid version. The IBM and updated predictions are for Q8, module A1A3, discrete version.

+: Predictions for the hybrid version of module A1A3 were not available for this analysis.

Table A2. Model 1, Critical Part Failure Rates

MODEL 1: MEASURED MODULE MTBF

Total number of failure data items, N	:	192
Total number of failures with module data, m	:	115
Total hours, nonfailure group, Ta	:	65,350,776
Scaled hours, nonfailure group, Tc	:	39,142,392
Total hours, failures with module data, Tmd	:	2,782,248
Sum of Tc and Tmd	:	41,924,640

MODULE	FAILURES	MTBF MEASURED	MTBF IBM PRED.(1975)	MTBF MIL-HDBK-217D
PS1/A2	19	2,206,560	845,881	718,344
A1A1	41	1,022,552	1,817,653	134,901
A1A2	34	1,233,078	734,694	1,227,039
A1A3	44	952,833	703,235	308,266
A3	23	1,822,810	714,321	568,476
A4	1	41,924,640	3,647,638	2,876,456
A5	2	20,962,320	4,650,081	3,116,236
Undet.*	19	2,206,560		

*: Undetermined includes unspecified connector failures, wire connections, etc., as well as failures with undetermined cause.

Table A3. Model 1 Module MTBF

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MODEL 1: OVERALL MTBF

MTBF Measured	MTBF IBM Pred. (1975)	MTBF MIL-HDBK-217D
368,753	156,138	65,396

Table A4. Model 1, Overall MTBF

MODEL 1: REFERENCE DESIGNATOR VS. MTBF

Ref.Des.	Failures	Operational Time (Days)	MTBF
114BPS5	1	348	8,352
178BPS1	6	41,713	166,852
130APS2	15	109,991	175,986
116BPS4	14	103,207	176,926
113APS5	12	107,899	215,798
116APS5	11	112,299	245,016
113BPS2	11	112,598	245,668
130APS4	9	109,690	292,507
113APS2	9	114,953	306,541
130BPS4	9	117,061	312,163
116BPS2	9	118,191	315,176
119BPS1	8	113,955	341,865
116APS2	8	116,034	348,102
114BPS4	8	120,036	360,108
115APS4	8	123,588	370,764
124APS2	6	121,427	485,708
130BPS2	6	121,550	486,200
114APS5	6	121,967	487,868
115BPS3	6	122,396	489,584
114APS2	6	123,225	492,900
115BPS1	6	124,150	496,600
114BPS2	6	126,178	504,712
113BPS5	4	119,672	718,032
119BPS3	2	75,554	906,648
115APS2	3	125,027	1,000,216
118APS4	2	122,168	1,466,016
119BPS2	1	77,227	1,853,448
119APS2	0	1830	<Infinite>

Table A5. Model 1, Reference Designator Vs. MTBF

MODEL 1A: MEASURED ELECTRONIC PARTS FAILURE RATES

Number of failures with module data	:	49
Number of failures with parts data	:	26
Scaled hours, nonfailure group, Td	:	10,041,160
Total hours, failures with parts data, Tpd	:	570,384
Sum of Td and Tpd	:	10,611,544

		Failure Rate		
		---- (Per Million Hrs.) ----		Experience
Part Code	Failures	Measured	MIL-HDBK-217D	Factor +
ACR1	3	.28271	.02482	.08779
ACR10	3	.28271	.02482	.08779
B0	7			
B7	5	#		
B9	1	#		
C0	14			
C4	1	.09424	.00010	.01061
CQ3	1	#		
D0	17			
DC1	5	.47119	.64042	1.3592
DHY1	2	.18847	---	---
DQ2	2	.18847	.00334 !	.01772
DT1	1	.09424	.31049	3.2947
E10	2	#		
EL1	2	.18847	.00019	.00101
ER1	1	#		
ER2	1	#		
ER8	1	.09424	.00075	.00796
ET1	2	.18847	.31013	1.6455
F0	12			
F3	1	.09424	---	---
FRC21	1	.09424	.00012	.00127

Table A6. Module 1A, Parts Failure Rates

MODEL 1A: MEASURED ELECTRONIC PARTS FAILURE RATES

		Failure Rate ---- (Per Million Hrs.) ---		Experience
Part Code	Failures	Measured	MIL-HDBK-217D	Factor +
FQ3	1	.09424	.00131	.01390
FU4	1	.09424	.02856	.30306
FU7	2	.18847	.00905	.04802
FVB1	2	.18847	.00576	.03056
G0	1			
H0	1			

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#: Please refer to the critical electronic part failure rate table.

!: This figure is for transistor Q8 on the discrete version of A1A3.

+: Experience Factor is the ratio of the MIL-HDBK-217D prediction to the measured failure rate

Table A6. Module 1A, Parts Failure Rates

MODEL 1A: CRITICAL ELECTRONIC PART FAILURE RATES

Component Group	Failures	---- Failure Rate (Per Million Hrs.) --- Measured	IBM Pred. (1975)	MIL-HDBK-217D
Main Switch Trans.	1	.09424	.78912	.02460
Input Capacitors	5	.47119	.21712	7.5312
Input Rectifiers	1	.09424	.01530	.00779
Primary Snubbers	4	.37695	.03628	.00644
Output Rectifiers	6	.56542	.16406	.04965
Output Capacitors	0	0.0	.40194	.05460
Aux. Switch Trans.	2 #	.18847	.03522 #	.00334 #
Aux. Hybrid	2	.18847	N/A +	N/A +
ICs, total	3	.28271	.46185	.22915
C1, A1A3	5	.47119	.01445	.64042

#: The two failures are for Q2, module A1A3, hybrid version. The IBM and updated predictions are for Q8, module A1A3, discrete version.

+: Predictions for the hybrid version of module A1A3 were not available for this analysis.

Table A7. Model 1A, Critical Part Failure Rates

MODEL 1A: MEASURED MODULE MTBF

Total number of failure data items, N	:	73
Total number of failures with module data, m	:	49
Total hours, nonfailure group, Ta	:	28,192,488
Scaled hours, nonfailure group, Tc	:	18,923,725
Total hours, failures with module data, Tmd	:	781,152
Sum of Tc and Tmd	:	19,704,877

		MTBF		
MODULE	FAILURES	MEASURED	IBM PRED.(1975)	MIL-HDBK-217D
PS1/A2	10	1,970,488	825,117	715,021
A1A1	13	1,515,760	1,736,473	121,310
A1A2	16	1,231,555	681,171	1,217,078
A1A3	24	821,037	665,031	293,448
A3	19	1,037,099	677,016	561,476
A4	1	19,704,877	3,545,471	2,863,524
A5	1	19,704,877	4,511,821	3,104,819
Undet.*	0	(Infinite)		

*: Undetermined includes unspecified connector failures, wire connections, etc., as well as failures with undetermined cause.

Table A8. Model 1A, Module MTBF

MODEL 1A: OVERALL MTBF

MTBF		
Measured	IBM Pred. (1975)	MIL-HDBK-217D
411,048	148,360	61,261

Table A9. Model 1A, Overall MTBF

MODEL 1A: REFERENCE DESIGNATOR VS. MTBF

Ref.Des.	Failures	Operational Time (Days)	MTBF
168CPS2	10	63,207	151,697
169CPS2	6	68,536	274,144
168DPS3	8	110,938	332,814
169DPS3	8	113,880	341,640
123CPS1	7	112,537	385,841
123CPS2	5	80,433	386,078
123DPS2	6	109,514	438,056
169DPS2	6	110,490	441,960
169CPS1	5	113,691	545,717
168CPS1	5	114,388	549,062
168DPS2	5	117,564	564,307
123DPS3	2	115,279	1,383,348
171APS2	0	896	<Infinite>
171APS4	0	896	<Infinite>
171BPS2	0	896	<Infinite>

Table A10. Model 1A, Reference Designator Vs. MTBF

MODEL 4B: MEASURED ELECTRONIC PARTS FAILURE RATES

Number of failures with module data	:	61
Number of failures with parts data	:	49
Scaled hours, nonfailure group, Td	:	15,343,169
Total hours, failures with parts data, Tpd	:	1,078,992
Sum of Td and Tpd	:	16,422,161

		Failure Rate		
		----- (Per Million Hrs.) ---		Experience
Part Code	Failures	Measured	MIL-HDBK-217D	Factor +
ACR1	1	.06089	.00296	.04861
ACR10	1	.06089	.00296	.04861
ACR4	2	.12179	.00454	.03728
ACR5	2	.12179	.00454	.03728
ACR6	2	.12179	.00454	.03728
ACR7	2	.12179	.00454	.03728
B0	3			
B7	9	#		
B9	2	#		
BC11	1	#		
BC13	1	#		
BC15	1	#		
BC16	1	#		
C0	9			
C3	1	.06089	---	---
C8	3	#		
CCR5	1	.06089	.00224	.03679
CCR7	3	.18268	.00224	.01226
D0	11			
D1	1	.06089	---	---
DC1	1	.06089	.53653	8.8115
DC2	1	.06089	---	---
DCR1	1	.06089	---	---
DHY1	3	.18268	---	---
DQ1	1	.06089	---	---
DQ2	5	.30447	.00313 !	.01028
DVR1	1	.06089	---	---

Table A11. Model 4B, Parts Failure Rates

MODEL 4B: MEASURED ELECTRONIC PARTS FAILURE RATES

Part Code	Failures	Failure Rate ----- (Per Million Hrs.) --- Measured	MIL-HDBK-217D	Experience Factor +
DVR2	1	.06089	---	---
E1	1	.06089	---	---
E10	1	#		
EC15	1	.06089	.00039	.00640
EC16	1	.06089	.00039	.00640
ET1	2	.12179	.31759	2.60769
F0	9			
F12	1	.06089	---	---
FC22	1	.06089	.00013	.00213
FC8	1	.06089	.00021	.00345
FCR2	1	.06089	.00015	.00246
FQ11	1	.06089	.01228	.20168
FR57	1	.06089	---	---
FR76	1	.06089	.00148	.02431
FR9	1	.06089	.00014	.00230
FU3	3	.18268	.02856	.15634
FU8	1	.06089	.01133	.18607
FU9	1	.06089	.01130	.18558
G0	1			
G2	1	.06089	---	---
G5	1	.06089	---	---
GC12	2	#		
GC13	1	#		
I0	3			
I5	1	.06089	---	---
IQ2	1	.06089	.00216	.03547
IU1	1	.06089	.02216	.36393
J0	7			
JC13	1	.06089	.00043	.00706

Table A11. Model 4B Parts Failure Rates

JC22	1	.06089	.00165	.02710
JC6	1	.06089	.00023	.00378
JQ1	1	.06089	.01074	.17638
JQ4	1	.06089	.01074	.17638
K1	1	.06089	---	---
K6	1	.06089	---	---

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MODEL 4B: MEASURED ELECTRONIC PARTS FAILURE RATES

#: Please refer to the critical electronic part failure rate table.

!: This figure is for transistor Q8 on the discrete version of A1A3.

+: Experience Factor is the ratio of the MIL-HDBK-217D prediction to the measured failure rate.

Table A11. Model 4B, Parts Failure Rates

MODEL 4B: CRITICAL ELECTRONIC PART FAILURE RATES

Component Group	Failures	--- Failure Rate (Per Million Hrs.) ---- Measured	IBM Pred. (1975)	MIL-HDBK-217D
Main Switch Trans.	3	.18268	.78912	.02460
Input Capacitors	13	.79161	.19360	6.7026
Input Rectifiers	2	.12179	.01236	.00687
Primary Snubbers	1	.06089	.03482	.00352
Output Rectifiers	10	.60893	.31870	.02435
Output Capacitors	3	.18268	.22164 *	1.6134 *
Aux. Switch Trans.	5 #	.30447	.03179 #	.00313 #
Aux. Hybrid	3	.18268	N/A +	N/A +
ICs, total	5	.30447	.86630	.30177
C1, A1A3	1	.06089	.01210	.53653

*: The IBM prediction for output capacitors is based on an A4 module from the Model 1 supply. The updated prediction is based on the output filter which appears in the schematic for the Model 4B.

#: The five failures are for Q2, module A1A3, hybrid version. The IBM and updated predictions are for Q8, module A1A3, discrete version.

+: Predictions for the hybrid version of module A1A3 were not available for this analysis.

Table A12. Model 4B, Critical Part Failure Rates

MODEL 4B: MEASURED MODULE MTBF

Total number of failure data items, N	:	114
Total number of failures with module data, m	:	61
Total hours, nonfailure group, Ta	:	35,696,352
Scaled hours, nonfailure group, Tc	:	19,100,680
Total hours, failures with module data, Tmd	:	1,191,432
Sum of Tc and Tmd	:	20,292,112

		MTBF		
MODULE	FAILURES	MEASURED	IBM PRED.(1975)	MIL-HDBK-217D
PS1/A2	9	2,254,679	539,444	388,117
A1A1	18	1,127,340	1,821,527	134,908
A1A2	16	1,268,257	672,875	1,210,918
A1A3	23	882,266	717,417	315,386
A3	21	966,291	511,716	313,100
A4	5	4,058,422	3,706,449	507,751
A6	6	3,382,019	980,162	1,219,438
A8	11	1,844,737	980,162	1,191,966
Undet.*	2	10,146,056		

*: Undetermined includes unspecified connector failures, wire connections, etc., as well as failures with undetermined cause.

Table A13. Model 4B Module MTBF

MODEL 4B: OVERALL MTBF

MTBF		
Measured	IBM Pred. (1975)	MIL-HDBK-217D
343,835	104,742 (*)	48,059

(*) For reference, the MIL-HDBK-217B analysis done at ARL, UT, on 2/9/78 for the Model 4B produced an overall MTBF figure of 28,059 hours.

Table A14. Model 4B, Overall MTBF

MODEL 4B: REFERENCE DESIGNATOR VS. MTBF

Ref.Des.	Failures	Operational Time (Days)	MTBF
119BPS3	1	1,103	26,472
111BPS3	9	100,245	267,320
118BPS3	10	112,025	268,860
111APS1	10	112,326	269,582
118APS1	10	115,870	278,088
118BPS2	10	117,744	282,586
112APS1	10	118,419	284,206
112BPS3	9	107,463	286,568
111BPS1	8	101,512	304,536
124CPS2	9	119,668	319,115
111APS3	8	111,101	333,303
118APS3	6	114,075	456,300
119APS2	5	107,172	514,426
112APS3	5	121,463	583,022
112BPS1	4	115,724	694,344

Table A15. Model 4B, Reference Designator Vs. MTBF

MODEL 4B: MEASURED MTBF VS. MANUFACTURE DATE

Manufacture Date	Spread Sheet Entries	Total Failures	Total Operating Time (Days)	Measured MTBF *	Normalized MTBF
7807-7812	55	3	111,941	895,528	1.00
7901-7906	72	9	128,287	342,099	.38
7907-7912	50	3	82,340	658,720	.74
8001-8006	72	9	104,070	277,520	.31
8007-8012	37	1	49,038	1,176,912	1.31
8101-8106	66	1	82,304	1,975,296	2.21
8107-8112	83	1	89,088	2,138,112	2.39
8201-8206	30	0	26,651	(Infinite)	----
8207-8212	73	1	58,157	1,395,768	1.56
8301-8306	65	0	34,549	(Infinite)	----
8307-8312	7	0	1,100	(Infinite)	----
8401-8407	21	0	612	(Infinite)	----

* Note: Due to incomplete data, these numbers are not accurate in the absolute sense. This is not a measure of achieved reliability, but does illustrate a reliability trend.

Table A16. Model 4B, Measured MTBF Vs. Manufacture Date

MODEL 4B: MEASURED MTBF VS. SHELF TIME

Shelf-Time (Days)	Spread Sheet Entries	Total Failures	Total Operating Time (Days)	Measured MTBF *	Normalized MTBF
150-249	69	1	98,200	2,356,800	1.00
250-349	173	5	215,296	1,033,421	.44
350-449	170	7	206,363	707,530	.30
450-549	125	5	148,114	710,947	.30
550-649	46	6	44,081	176,324	.07
650-749	18	3	15,862	126,896	.05
750-849	4	1	4,877	117,048	.05
850-949	7	0	8,822	(Infinite)	----
950-UP	3	0	2,696	(Infinite)	----

* Note: Due to incomplete data, these numbers are not accurate in the absolute sense. This is not a measure of achieved reliability, but does illustrate a reliability trend.

Table A17. Model 4B, MTBF Vs. Shelf Time

	MODLE 1	MODEL 1A	MODEL 4B	CUM.
ASMAN ENTRY	59	34	37	130
IBM RN	49	21	25	95
% IN IBM DATA	83.1%	61.8%	67.6%	73.1%

ADJUSTED MTBF

	ADJUSTMENT FACTOR	ADJUSTED FAILURES	ADJUSTED MTBF
MODEL 1	$\frac{1}{.831} = 1.2$	1.2*189=227	$\frac{69,694,416}{227} = 307,024$
MODEL 1A	$\frac{1}{.618} = 1.62$	1.62*72=117	$\frac{29,595,480}{117} = 252,953$
MODEL 4B	$\frac{1}{.676} = 1.48$	1.48*110=163	$\frac{37,821,840}{163} = 232,036$

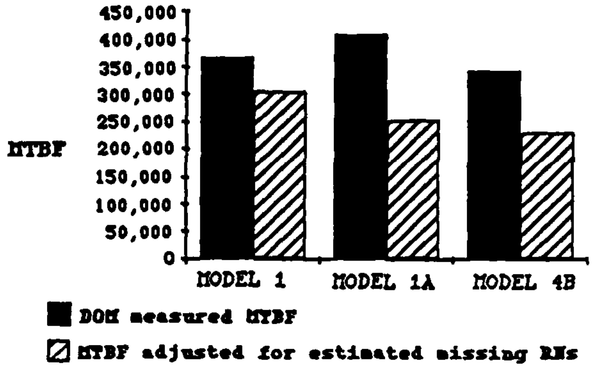

Table A18. Adjustment to calculated MTBF for estimated missing Reject Notices.

RESULTS OF CALCULATIONS OF THE LOWER 99% CONFIDENCE LIMIT

The modified MTBF was adjusted by the factor for the 99% lower confidence limit. A normal approximation was used to calculate the Chi-square alpha point which was used in the formula for the lower confidence limit. The table below shows the results of the calculation.

Model	Degrees of Freedom	2T	Chi-Square Value	Lower Confidence Limit
1	456	139,388,830	237.56	259,301
1A	236	59,190,960	295.73	200,152
4B	328	75,643,680	397.74	232,036

The resulting adjustment to the lower confidence limit is shown on the bar graph in the section entitled "Brief Summary of Results."

Table A19. Calculations, Lower 99% Confidence Limit

MODEL 4B: FAILURE MODES FOR SUPPLIES WITH GREATER THAN 350 DAYS SHELF TIME

FAILED PS SN	SHELF TIME	MODULE CODE	PART CODE	DESCRIPTION
955	383	....	no data	....
992	417	C	C8	Main transistor switches
526	426	G	GC12	Aluminum elect. capacitor
536	426	F	FR9	Resistor, MF
803	439	....	no data	....
1252	448	F	FC8	Ceramic cap.
1384	454	....	no data	....
902	456	....	no data	....
845	460	F	FC22	Glass cap.
779	464	....	no data	....
970	506	F	FU3	Linear IC
		K	K1	Solder conn.
732	558	F	FQ11	Small signal transistor
		D	DQ2	Switch trans.

Table A20. Model 4B, Failure Modes With Greater Than 350 Days Shelf Time

MODEL 4B: FAILURE MODES FOR SUPPLIES WITH GREATER THAN 350 DAYS SHELF TIME

FAILED PS SN	SHELF TIME	MODULE CODE	PART CODE	DESCRIPTION
766	559	....	unspecified	....
812	566	....	unspecified	....
962	589	F	FU3	Linear IC
548	599	....	unspecified	....
701	602	I	I5	Assembly error
532	709	....	no data	....
927	741	B	BC16	Aluminum electronic cap.
561	742	A	ACR1, AC10	Output rectifier diodes
613	762	J	JC13	Ceramic cap.

Table A20. Model 4B, Failure Modes With Greater Than 350 Days Shelf Time

INSTALLATION TO LIGHT-OFF (POWER-UP) DELAY TIME

HULL	DELAY Months	DELAY Days
594	8	243
595	12	365
603	14	426
604	12	365
605	6	183
607	(AVG)	196
613	5	152
614	1	30
615	11	335
621	3	91
637	2	61
638	(AVG)	196
646	9	274
648	5	152
650	(AVG)	196
651	6	183
653	(AVG)	196
660	(AVG)	196
663	(AVG)	196
664	10	304
665	5	152
666	8	243
667	10	304
669	5	152
670	3	91
671	10	304
673	2	61
674	4	122
675	4	122
676	3	91
677	3	91
678	5	152
679	7	213
680	11	335
681	12	365
682	12	365
683	(AVG)	196

Table A21. Installation to Light-Off (Power-up) Delay Time

INSTALLATION TO LIGHT-OFF (POWER-UP) DELAY TIME

HULL	DELAY Months	DELAY Days
684	5	152
685	5	152
686	(AVG)	196
687	11	335
691	(AVG)	196
694	(AVG)	196
695	(AVG)	196
696	(AVG)	196
697	(AVG)	196
699	(AVG)	196
700	(AVG)	196
701	(AVG)	196
702	0	0
703	9	274
704	10	304
705	5	152
706	11	335
707	0	0
708	4	122
709	5	152
710	2	61
711	(AVG)	196
712	1	30
713	3	91
714	6	183
715	4	122
716	(AVG)	196
717	8	243
718	11	335
719	(AVG)	196
720	(AVG)	196
721	(AVG)	196
722	(AVG)	196
724	4	122
750	(AVG)	196
SYS D1	(AVG)	196
SYS D3	(AVG)	196

Table A21. Installation to Light-Off (Power-up) Delay Time

The AN/BQQ-5 power supplies analyzed violated the NAVMAT guidelines to the extent shown below. The table shows the components that were overstressed in each of the three types of power supplies. None of the components in any of the three power supplies failed part quality criteria. All of the components that violated NAVMAT stress guidelines in the supplies examined were resistors.

AN/BQQ5 NAVMAT Stress Deviations

MODEL	ASSEMBLY	COMPONENT	TYPE	ACTUAL STRESS	NAVMAT GUIDELINE
1	A1	R4	RNR55	.600	.50
1	A1A1	R1	RNR55	.560	.50
1	PS1/A2	R1-R4	RWR81	.550	.50
1A	A1A1	R1	RNR55	.560	.50
1A	PS1/A2	R1-R4	RWR81	.550	.50
1A	A3	R4	RNR55	.600	.50
4B	A1A1	R1	RNR55	.560	.50
4B	PS1/A2	R1-R4	RWR81	.550	.50
4B	A3	R4	RNR55	.600	.50
4B	A3	R41	RNR55	.740	.50

Table A22. Components in the AN/BQQ-5 that exceed NAVMAT P4855-1 guidelines

END

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